Oklahoma Disaster Management

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Three-Dimensional Visualizations of Convective Instability Parameters for the improvement of Oklahoma Disaster Management

August 5, 2004

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Abstract

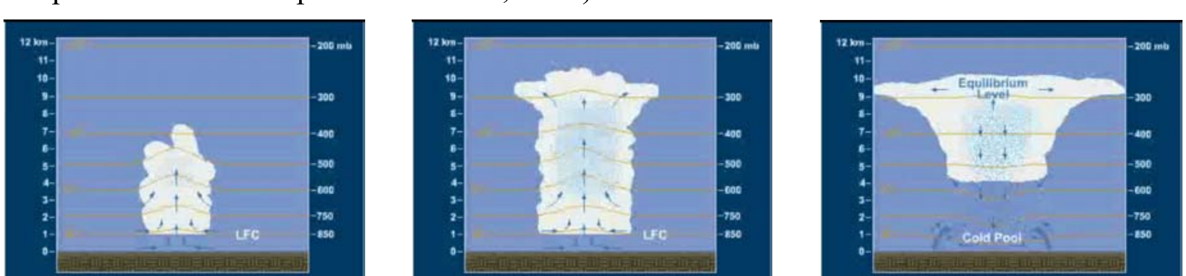
Millions of dollars are spent each year by the state of Oklahoma to repair property damage caused by severe storms and tornadoes. Being at the heart of the region known as Tornado Alley, improving storm prediction capabilities is one of the primary concerns of the citizens of Oklahoma. Meteorologists have linked the abundance of storms in Oklahoma to the mixing of moist air from the Gulf with dry air that occurs over this region. This mixing process is the catalyst for convection, the process responsible for the formation of storms. More specifically, convection is the cyclical process of rising warm, moist air through cool air masses, and the falling of cool air through those same warm air masses. Experiments, such as the International H_20 Project (IHOP) and the Oklahoma Mesonet, have started to gather data concerning convection during severe storm formation that plagues this region. The studies done on these individual sets create valid conclusions that do not quite cover the entire view of convection. To address this issue, a new study was started, comparing multiple data sets. The data used in this study were gathered not only from IHOP and the Oklahoma Mesonet, but also from NASA Missions, such as the TERRA satellite. Visuals were produced using *Maya 4.5 Complete,* and *Corel Bryce 5*, combining cloud cover depictions collected from the GOES-8 satellite, total column precipitable water vapor data from the MODIS instrument on the TERRA mission, surface water vapor and equivalent potential temperature data derived from the Automated Surface Observing System, and vertical water vapor profiles measured by the Lidar Atmospheric Sensing Experiment (LASE) instrument. These LASE profiles pertain to water vapor in some way, either being relative humidity, water vapor mixing ratio, or equivalent potential temperature. In addition to the visuals created using individual data sources, visuals have been made in *Integrated Data Viewer* (IDV) using data from the Rapid Update Cycle (RUC) model. The visuals were compared showing the inconsistencies between the two different sources, making plain the need for improvements in this model.

Background and Introduction

The Southern Great Plains region is known for its frequent tornadoes. Due to the frequency at which these tornadoes occur, the entire region from the Texas panhandle to northern Kansas has been named "Tornado Alley." Lying in the very heart of this region is the state of Oklahoma, the most tornado-ridden area in the United States. From a statistical standpoint, the citizens of Oklahoma suffer an average of 19.7 tornadoes per 10,000 square miles based on data from the years 1880-1989. This ratio translates into roughly 54 tornadoes a year (Clark, 1999). Despite that yearly average, storm cells in the region have been known to produce in excess of 50 tornadoes in a single day (Terp, 2000). A perfect example of this extreme is May 3, 1999, when a total of 66 tornadoes touched down across Oklahoma and Kansas. These tornadoes killed 46 people, injured 800, and ultimately resulted in over 1.5 billion dollars in damages (Terp, 2000). Recognizing the extent of this damage, the citizens of Oklahoma are greatly concerned with improved storm prediction.

Scientists have conducted extensive research to understand the correlation between the formation of severe storms and deep convection in the atmosphere. Convection, or the cyclical process of rising warm, moist air through cooler, dry air, and the falling of cool air through warm air masses, occurs frequently in the region surrounding Oklahoma due to the mixing of dry air from the Rocky Mountains and moist air from the Gulf of Mexico. Under prime conditions, deep convective cells often form and lead to severe storms.

Several factors must exist simultaneously in the atmosphere in order for these tornadic storms to develop from convection. These factors include atmospheric instability, the presence of moisture, and a lifting mechanism to initiate the convection process (NOAA, 2003). The lifting mechanism causes convection to begin by forcing parcels of air above the level of free convection, or the atmospheric level where the parcel of air does not have to expend any energy to rise. Once the parcels of air reach this level, they continue to rise until reaching equilibrium, or the level at which the ambient temperature is equal to that of the rising parcel. However, due to the momentum already possessed by the parcel, the parcel will rise above the equilibrium level and spread, forming the typical anvil shape of a storm cloud. After rising above the equilibrium level, the parcel will then descend and begin an oscillating pattern that allows for moisture to condense, resulting in precipitation down through the upward drafts (University Corporation for Atmospheric Research, 2003).

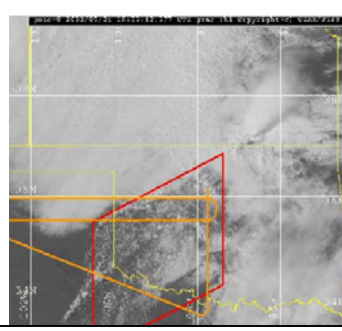


The Convection Process

Since scientists do not have a concrete understanding of the process of convection, and how water vapor impacts the development of deep convection, several efforts have been undertaken to gather more data to aid this understanding. The International H_2O Project (IHOP) and the Oklahoma Mesonet are two such endeavors that have gathered vast amounts of data that are now readily available for use and interpretation. IHOP was an international project that was composed of over 200 scientists representing the United States, France, Germany, and Canada (Parsons and Weckworth, 2002). A portion of the project utilized NASA's Lidar Atmospheric Sensing Experiment (LASE), which is an airborne Differential Absorption Lidar (DIAL) system developed at NASA Langley Research Center for measuring water vapor profiles (Browell et al., 1997; About Lidar Data, 2002). The Differential Absorption Lidar (DIAL) technique, works by emitting two pulses of light at different wavelengths and then measuring the difference between the intensities of the return signals (Kavaya, 1999). Computer processing determined the concentration of the targeted water vapor molecules as a function of altitude, and reported any use for data interpretation.

In contrast to the air-borne sensors, such as the DIAL instrument, the Oklahoma Mesonet observes current weather from 110 automated monitoring stations across Oklahoma (Oklahoma Mesonet, 1996-2004). "Mesonet" is derived from the terms "mesoscale," which refers to weather events ranging in size from a few kilometers to several hundred kilometers and lasting from several minutes to several hours in duration, and "network" (Oklahoma Climatological Survey, 2003). The objective of the Oklahoma Mesonet is to observe and measure the environment during mesoscale events. The automated, ground-based stations observe the atmosphere in five-minute intervals and transmit the observations to a central facility where the data is compiled and provided to customers. Through the use of data, such as that gathered by IHOP and the Oklahoma Mesonet, the process of convective initiation can be better understood and improved predictions can be produced. Currently, models such as RUC (Rapid Update Cycle) are used to help forecasters predict where and when convection will occur. However, these mathematical models are not perfect and require modifications and so the, RUC is no exception.

Based on the general need for improving the knowledge of convective processes, the Oklahoma Disaster Management project was formed by the DEVELOP program in the summer of 2003. The project conducted a case study of convection to expand the general understanding of convection, in turn forecasters will be able to improve the accuracy of storm watch boxes and limit storm warnings to only those areas where danger is imminent. Through the use of three-dimensional visualizations, this project clearly and understandably demonstrated convective instability parameters. The use of combined NASA and non-NASA datasets allowed the Oklahoma Disaster Management project to demonstrate several different parameters and their interactions. This project will also benefit policy-makers by aiding them in severe weather related decisions.



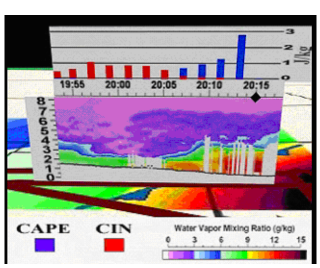
Storm Watch-Box of Convection

Methods

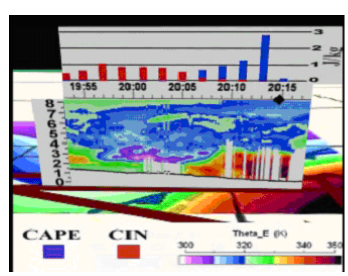
On May 24, 2002, and June 9, 2002, the atmospheric conditions over the plains of Oklahoma were somewhat similar. Water vapor, aerosol levels, and equivalent potential temperatures, which are all parameters for convection, were alike on the two days, yet tornadoes formed on May 24th, and none formed on June 9th. Therefore, researchers began examining the dynamics of the two days. The approach used to accomplish this was to create three-dimensional visualizations that aid adept meteorologist's/scientist's perception of convection parameters.

Visuals for June 9, 2002, were made using a three-dimensional animation program, *Corel Bryce 5*. *Bryce* was used namely because it was a relatively easy program to use and also allowed for the direct importing of images. LASE water vapor profiles and MODIS total precipitable water vapor were used to aid in the visualizing of water vapor's effect on convective initiation. The LASE profiles allowed for vertical understanding of water vapor in the situation on June 9th, and the MODIS water vapor data granted the horizontal view of the area. Since both the LASE and MODIS data were images, the separate images were placed into *Bryce* and then manipulated into a time lapse. The LASE profiles were geo-referenced to correspond to the flight path of the DC-8 plane which gathered the IHOP measurements, and the MODIS image placed as a ground image. Using camera functions, a 3-D fly-through was created and displayed in January at the 2004 American Meteorological Society Annual Conference.

The visuals for May 24, 2002, were created using slightly different convective instability parameters, like CAPE and CIN, whose understanding will in turn be furthered by the visuals. Convective Available Potential Energy (CAPE) represents the potential energy possessed by a parcel of air, while Convective INhibition (CIN) is a measure of the amount of energy a parcel of air must expend to reach the level of free convection. Higher CAPE values for a given area heighten the chance for deep convection to occur, while higher CIN inhibits convection. These two convective initiation instability parameters were measured by IHOP in addition to the other measurements taken on their flights. In addition to these two parameters, there are LASE vertical profiles of water vapor mixing ratio and equivalent potential temperature depicted in visuals. Equivalent potential temperature was a measure of atmospheric temperature if a particular parcel of air is taken adiabatically to 1,000 millibars of pressure and all the water vapor was removed. Establishing equivalent potential temperature made it possible to compare the temperature of different parcels of air despite variations in temperature that occur at different altitudes and different amounts of water vapor in the air. Finally, ground images were derived from the Oklahoma Mesonet using *Gempak*, a meteorological data manipulation program. The images showed water vapor mixing ratio and equivalent potential temperature from the general times when the LASE data were gathered.



Water Vapor Mixing Ratio



Equivalent Potential Temperature

After the LASE and Mesonet data were gathered and placed into a series of images, visuals were made using a different three-dimensional animation program, *MAYA 4.5 Complete*. *MAYA* provided more fly-through and 3-D options than *Bryce*, which resulted in higher quality animations. All of the parameters were compiled into two visuals using *MAYA*, one for water vapor mixing ratio, and a second for equivalent potential temperature. The visuals were made in identical fashion to demonstrate the relationship between the two variables. The horizontal images, generated from Mesonet data, were faded in, originally in a video created in *Macromedia Flash MX*, but ultimately through the use of *Maya*'s tools.

A concern with the first May 24th visuals were the horizontal images, the Mesonet images, which only covered the state of Oklahoma, whereas the DC-8 flight aircraft flew over other states. To correct this issue, data was added from the Automated Surface Observing System (ASOS), a network of nation-wide weather observing stations updated every hour. Water vapor mixing ratio and equivalent potential temperature was made into images using *Gempak*. Another advantage of using ASOS data was that, through its use, the visuals could show conditions before and after the LASE measurements were taken. The ASOS data was ultimately used to replace the Mesonet images since it was more complete than the Mesonet data.

The ASOS and LASE images began with a simple world map and the flight path for the DC-8 plane on May 24, 2002. As the camera zoomed into the Oklahoma panhandle and surrounding area, the first of the ASOS images begin to fade into view. The images fade between 1500 UTC and 2300 UTC, showing overall conditions at ground level. When the ASOS images reach 1900 UTC, the view comes down from the overhead view as the LASE vertical profile rises. The vertical profile also has an altitude bar, a time scale, and an overhead area where the bar graphs of CAPE and CIN appear. A slider appeared to show the progression of time between 1953 UTC and 2018 UTC. CAPE and CIN values rise from the profile every two minutes along that segment of the flight path. Once the time passed, the camera came back to its original position and the remaining images faded in and out, ending in a black out.

In the final phase of the project, visuals were remade for May 24th, incorporating the same ASOS images with wind barb data superimposed on top of the water vapor mixing ratio or the equivalent potential temperature data. Additionally, a visual was made for relative humidity, another way of expressing moisture in the atmosphere, in identical manner to the previous visuals. Visualizations were made in Integrated Data Viewer (IDV) using data gained form the Rapid Update Cycle (RUC) model.

Results

Upon comparing the two visualizations for May 24, 2002, it can be seen that greater values of CAPE occur at locations where there is greater water vapor mixing ratio and equivalent potential temperature at lower altitudes. This suggests that the air is rather unstable and is prime for severe storms to form.

On the west side of the vertical east-west cross section the values of CIN are much greater than those of CAPE, in fact the CAPE values are hardly visible in the images. One can see that the values of both water vapor mixing ratio and equivalent potential temperature are both proportionally lower on the left, where CIN overrides the

CAPE, than on the right were the opposite occurs. Thus, the atmosphere is stable in this region.

As the water vapor mixing ratio and equivalent potential temperature are greater, the point values of CAPE increase dramatically. Additionally, corroboration of the data is shown in that the ASOS ground images match up exactly to the vertical profiles at ground level.

Conclusions

The identical nature of the visualizations of the equivalent potential temperature and water vapor mixing ratio for May 24, 2002 aid observers in perceiving similarities. Greater values of CAPE occur at locations where there is greater water vapor mixing ratio and equivalent potential temperature at lower altitudes. The lower values of CAPE and corresponding higher values of CIN occur to the Western side of the flight path, where no convection formed. Also, the values of water vapor mixing ratio and equivalent potential temperature are both proportionally lower on the left, where CIN overrides the CAPE. As the measurements of water vapor mixing ratio and equivalent potential temperature increase, so too does the CAPE. This relationship implies that the greater the moisture and equivalent potential temperature, the greater the chance for deep convection to occur.

In the ASOS images, the progression of the cold fronts and dry lines were seen as time passes. At the beginning the two are separate, but as time goes on they come closer and closer to one another until the two are touching, creating an environment perfect lifting mechanism, force for unstable air to rise. As seen in the visuals, the areas where large values of CAPE occurred were to the east of the dry line and cold front. This shows that the convergence allowed for the CIN to be overridden, generating an unstable environment where deep convection could and, in the case of May 24th, did occur.

In addition to the cold front and dry line shown in the ASOS images, wind barb data could also be seen. As time passed, the winds in the northern area under observation shifted from a south-southwest direction to a more a southern direction. On the other side of the cold front, winds moved to meet the line and were turned around. Thus it can be seen that as time passed, the cold front forced winds to change directions, almost causing a visible counter-clockwise rotation behind the convergence of the cold front and dry line.

Upon the completion of all visuals, the team will undertake a specific study comparing the ASOS and IHOP data to the RUC model. The objective will be to study the similarities and differences in the different data sources. The team expects that there will be differences in areas where convection occurred. The team will demonstrate to meteorologists that through the use of more specific data sources, predictive capabilities may improve.

Project Summary

Throughout the 2004 summer weeks of the DEVELOP program, the Oklahoma Disaster Management team has sought to aid scientist in better understanding convective initiation through creating accurate and comprehensive 3-D visualizations. More specifically, the team desired to further understand how convective initiation parameters cause tornadoes and severe storm formation. The collaboration of every team-member, a coalescence of a variety of backgrounds, experiences, and interests, helped to achieve the research goals and visualizations. Two of the projects main products include the ASOS and RUC visuals, which are scientifically significant as well as visually pleasing. Therefore, through diligent team work the goal of aiding our scientific peers in perceiving 3-dimensional distribution of convective instability parameters was met and surpassed as both the scientific community as well as the general public will come to better understand factors in convective initiation - water vapor mixing ratio, equivalent potential temperature, relative humidity, CAPE, and wind bars. The bridging of the gap between these communities will allow policy makers and scientists to collaborate to make better decisions on storm prediction.

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